EXPERIENCES WITH REMOTE ELECTRON MICROSCOPY

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With the advent of a rapidly proliferating international computer network, it has become feasible to consider remote operation of instrumentation that is normally operated locally. For modern electron microscopes, the growing automation and computer control of many instrumental operations has facilitated the task of providing remote operation.

The National Center for Electron Microscopy was established as a user facility with the goal of providing the materials science community with state of the art high-resolution and high-voltage transmission electron microscopy (HR-TEM and HV-TEM). In order to facilitate use of NCEM TEMs by distant users, a project was instituted to place a unique instrument, a Kratos EM-1500 operating at 1.5MeV, on-line for remote use. The first public demonstration of remote use of the Kratos occurred in 1995, when it was operated over a distance of 2000 miles, from Kansas City[1]. In this demonstration, a specimen of an Al/Pb alloy was heated *in situ* and observed under remote control, with remote-operator control of heating rate, microscope focus, and stage movement (translation and tilt). In addition, an LBNL-developed drift correction was implemented locally to assist the remote operator by controlling heating-induced movement of the specimen. Automated drift correction was essential in enabling the remote operator to maintain control at the then network-limited video reception rate of one to two frames per second.

Around the same time, other materials science teams were demonstrating telepresence for analytical electron microscopy[2] and remote-access high-resolution electron microscopy[3]. There was also an early effort to establish remote electron microscopy for the biological sciences[4]. In 1996, we demonstrated an improved user interface for the Kratos[5]. In the same year, the Materials Microcharacterization Collaboratory (MMC) was created as a pilot project within the US Department of Energy's DOE2000 program. The DOE2000 program was set up to establish national collaboratories to provide access via the Internet to unique or expensive DOE research facilities as well as to expertise for remote collaboration, experimentation, production, software development, modeling, and measurement. More than mere remote access to instrumentation, collaboratories such as the MMC are also designed to benefit researchers by providing tools for video conferencing, shared data-viewing, and collaborative analysis of results.

The MMC project[6] united four DOE BES electron microscopy user centers, located at ANL, LBNL, ORNL and the University of Illinois, with the DOE EE user center located at ORNL. The MMC linked these organizations into one virtual on-line interactive Materials Microcharacterization Collaboratory able to bring the microcharacterization and microanalysis tools that are available in national centers to geographically dispersed researchers working in industries, universities, and Government laboratories. It enabled these remote users to share on-line the instrumentation, knowledge and expertise available at the individual facilities making up the Collaboratory. LBNL's contribution to the MMC's on-line instrumentation included the Kratos EM-1500 and a modified Philips CM300 TEM (the instrumental half of the One-Ångstrom Microscope project[7]).

A major LBNL contribution to the MMC was construction of DeepView[8], a microscope-independent computer-control system that could be ported to other MMC members to provide a common graphical user-interface (GUI) for control of any MMC instrument over the wide area network[9]. To be useful, DeepView was designed to be cross-platform (able to work on a range of computers) and cross-microscope (able to control many kinds of TEMs and SEMs as well as their attached detectors such as EDS, GIF, PEELS, bi-prisms, and CCDs). DeepView was designed to be intelligent enough to present the user with control windows for every type of special feature available on the currently-accessed microscope, at the same time not presenting controls for features not available.

An additional design requirement for DeepView required it to be simple enough to enable a user not familiar with that particular microscope to perform basic microscopy remotely, but sufficiently sophisticated so that expert users can exploit the full potential of the instrument. Correspondingly, it allows the user to choose between using a generic interface and one customized to appear like a direct local control for that particular make and model of microscope. It can allow the user to choose the preferred mode of operation of basic controls, something as simple as moving the specimen stage by moving slide bars in x and y, or by drag-and-drop on the live image, or by mouse click on the portion of the image to be moved to the center of view. It is modular and flexible, and should be able to accommodate new instruments such as the coming generation of high-resolution microscopes with auto-alignment and aberration-correction. DeepView has been used successfully to control TEMs (Kratos and CM300) at Berkeley and an XL30 SEM at Oak Ridge. DeepView is available to the microscope community[10].

Remote electron microscopy was pioneered by research groups in universities and government laboratories[1-4]. More recently however, demand for its advantages, and the relative ease of adding this feature to already-existing computer control, has spurred microscope manufacturers to add this facility to their latest-generation electron microscopes[11-13]. In the future, it is possible that much routine electron microscopy will be carried out by users sitting at their desks, manipulating the microscope via one control window on their computer desktop, perhaps communicating with collaborators in a second window, and analyzing their results in a third.

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